[0040] According to one such embodiments of the present invention, it ~~may be preferable~~ is necessary that the microstructure includes polygonal ferrite and a hard second phase, and the hard second phase is either martensite or bainite. When the hard second phase is martensite, since martensite has greater volumetric expansion and allows the introduction of a larger number of mobile dislocations than bainite, the yield point can be further lowered and the BH amount can be increased. Therefore, the hard second phase may likely be martensite. However, residual austenite is allows up to about 3%, which is the level at which it is likely unavoidably contained.

[0041] As described above, it is ~~preferable~~ required that the volume fraction of the second phase is 3 to 20% and the hardness ratio is 1.5 to 6 in order to realize both processability and superior bake hardenability after aging.

[0044] On the other hand, the main phase can be made to be polygonal ferrite in order to obtain superior processability, and in addition, in order to obtain this effect, it is ~~preferable~~ necessary that the grain size ratio of the polygonal ferrite to the second phase is 1.5 or more. In the case in which the grain size ratio of the polygonal ferrite to the second phase is less than 1.5, ductility decreases due to the influence of the hard second phase. Furthermore, if the hard second phase is a phase in which dissolved elements can be concentrated, and hardness may have increased in the manner of martensite, the grain size of the second phase inevitably may become smaller. Since this results in greater resistance to the effects of the hard second phase. Thereby, ductility can be improved, the crystal grain size is preferably 2.5 or more.

[0072] It is ~~preferable~~ necessary to suitably promote ferrite transformation after completion of rolling in order to obtain the desired fractions of the microstructure and hardness

ratio between the main phase and the second phase in this component system. Therefore, it is ~~beneficial~~ necessary that the finish rolling be carried out under conditions in which a sum of reduction rates of the final stage and the stage prior thereto is 25% or more. When the reduction rate of the final stage is less than 1%, the flatness of the steel sheet deteriorates, while in the case in which it exceeds 15%, ferrite transformation proceed significantly. Thus, the desired microstructure in which the grain size ratio of the polygonal ferrite to the second stage is 2.5 or more may not be obtained. Therefore, the reduction rate of the final stage should be 1 to 15%. An upper limit may not be particularly provided for the sum of reduction rates of the final stage and the stage prior thereto; however, it is preferably 50% or less in consideration of equipment restrictions due to rolling reaction force.

Table 3-1

	Production Conditions				
	Slab No.	Heating rough rolled bar	Temperature at start of finish rolling (°C)	Ar_3+250 (°C)	(Reduction rate of final stage)/(Sum of reduction rates of final stage and stage prior thereto) (%/%)
Ex.1	X1	Yes	1100	1044	14/36
Ex.2	X1	No	1100	1044	14/36
~~Ex.3~~	~~X2~~	~~No~~	~~1100~~	~~1094~~	~~10/24~~
Ex.4	X3	No	1100	1059	10/24
~~Ex.5~~	~~X4~~	~~No~~	~~1100~~	~~1068~~	~~10/24~~
~~Ex.6~~	~~X5~~	~~Yes~~	~~1100~~	~~1053~~	~~10/24~~
Ex.7	X6	Yes	1100	1043	14/36
Ex.8	X7	Yes	1100	1038	14/36
Ex.9	X1	Yes	<u>980</u>	1044	14/36
Ex.10	X1	Yes	1000	1044	14/36
~~Ex.11~~	~~X7~~	~~Yes~~	~~1100~~	~~1038~~	~~14/36~~
~~Ex.12~~	~~X8~~	~~Yes~~	~~1100~~	~~1015~~	~~14/36~~
Comp.Ex.1	X1	Yes	1100	1044	<u>16/22</u>
Comp.Ex.2	X1	Yes	1100	1044	14/36
Comp.Ex.3	X1	Yes	1100	1044	14/36
Comp.Ex.4	X1	Yes	1100	1044	14/36
Comp.Ex.5	X1	Yes	1100	1044	<u>18/36</u>
Comp.Ex.6	Y1	No	1100	1136	14/36
Comp.Ex.7	Y2	No	1100	1038	14/36
Comp.Ex.8	Y3	Yes	1100	1014	10/26

Table 3-1 (Continued)

	Production Conditions								
	FT (°C)	Ar_3 (°C)	Ar_3+100 (°C)	Ar_1 (°C)	MT# (°C)	Holding time (sec)	Cooling rate from holding temp. to 350°C (°C/sec)	CT (°C)	Comments
Ex.1	850	794	894	712	720	4.0	120	<150	
Ex.2	850	794	894	712	720	4.0	120	<150	
~~Ex.3~~	~~870~~	~~844~~	~~944~~	~~722~~	~~740~~	~~5.0~~	~~110~~	~~200~~	~~*1~~
Ex.4	870	809	909	714	720	5.0	110	200	
~~Ex.5~~	~~870~~	~~818~~	~~918~~	~~714~~	~~730~~	~~5.0~~	~~110~~	~~200~~	
~~Ex.6~~	~~870~~	~~803~~	~~903~~	~~713~~	~~730~~	~~5.0~~	~~110~~	~~200~~	
Ex.7	850	793	893	711	720	5.0	110	200	
Ex.8	850	788	888	710	720	5.0	110	200	*2
Ex.9	850	794	894	702	710	4.0	120	<150	
Ex.10	850	794	894	702	710	4.0	120	<150	
~~Ex.11~~	~~850~~	~~788~~	~~888~~	~~710~~	~~740~~	~~1.5~~	~~100~~	~~250~~	
~~Ex.12~~	~~850~~	~~765~~	~~865~~	~~706~~	~~720~~	~~4.0~~	~~100~~	~~<150~~	
Comp.Ex.1	850	794	894	712	780	4.0	120	<150	
Comp.Ex.2	780	794	894	712	720	4.0	120	<150	
Comp.Ex.3	850	794	894	712	780	0.5	120	<150	
Comp.Ex.4	850	794	894	712	720	4.0	10	500	
Comp.Ex.5	850	794	894	702	710	4.0	120	<150	
Comp.Ex.6	890	886	986	749	750	4.0	120	<150	
Comp.Ex.7	850	788	888	710	720	4.0	120	<150	
Comp.Ex.8	875	764	864	751	760	5.0	110	400	

*1: Descaling was carried out after rough rolling under conditions of a collision pressure of 2.7 MPa and a flow rate of 0.001 liters/cm^2.

*2: The sheet was passed through a zinc plating step.

Table 3-2

	Microstructure				Mechanical Properties			Bake Hardenability	
	Microstructure	volume fraction of Second phase (%)	Hardness ratio	Crystal grain size ratio	YP (MPa)	TS (MPa)	El (%)	2%BH (MPa)	2%BH after artificial aging (MPa)
Ex.1	PF+M	10	3.7	2.7	295	461	36	79	78
Ex.2	PF+M	8	3.9	2.8	289	456	35	81	81
~~Ex.3~~	~~PF+B~~	~~13~~	~~2.9~~	~~2.9~~	~~288~~	~~416~~	~~35~~	~~68~~	~~66~~
Ex.4	PF+M	8	3.8	2.8	312	488	32	91	88
~~Ex.5~~	~~PF+B~~	~~12~~	~~3.2~~	~~2.9~~	~~290~~	~~442~~	~~34~~	~~80~~	~~77~~
~~Ex.6~~	~~PF+B~~	~~14~~	~~2.7~~	~~2.7~~	~~320~~	~~491~~	~~32~~	~~77~~	~~70~~
Ex.7	PF+M	9	3.8	3.0	320	460	35	88	86
Ex.8	PF+M	10	3.6	2.9	324	471	34	80	80
Ex.9	PF+M	9	3.8	2.8	293	470	34	71	65
Ex.10	PF+M	6	4.1	2.9	297	460	33	74	63
~~Ex.11~~	~~PF+B~~	~~16~~	~~2.6~~	~~1.9~~	~~316~~	~~466~~	~~33~~	~~61~~	~~62~~
~~Ex.12~~	~~PF+B~~	~~18~~	~~1.8~~	~~1.8~~	~~344~~	~~481~~	~~31~~	~~64~~	~~61~~
Comp.Ex.1	BF	100	1.0	--	322	456	33	58	56
Comp.Ex.2	Processed F+M	5	1.2	2.6	389	470	28	61	58
Comp.Ex.3	BF	100	1.0	--	318	460	31	60	55
Comp.Ex.4	PF+P	12	1.4	2.7	311	439	32	21	8
Comp.Ex.5	PF+B	5	4.0	1.4	320	460	31	55	45
Comp.Ex.6	PF+M	2	2.7	2.2	410	570	24	12	10
Comp.Ex.7	PF+M	11	3.6	2.6	303	465	34	76	36
Comp.Ex.8	PF+B +13%γR	31	2.1	1.8	566	794	33	46	43

In the table, γR indicates residual austenite.